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Design and Integration Issues for Visually Coupled Systems

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This is a briefing on design and integration issues for visually coupled systems that was presented to AATC (The Air National Guard/Reserve Test Center/Tuscon AZ).

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Design and Integration Issues for Visually Coupled Systems

5 December 2005

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Design and Integration Issues of Visually Coupled Systems

- Display Characteristics
  - Brightness
  - Resolution
  - Acuity
  - Size / Field of View (FOV)
  - Color vs. Monochrome
- Visor / Combiner
  - Standard vs. Custom Visor
  - Visor Projected Vs. Combiner Projected
  - Image Pre-distortion (warping) Requirements
  - Eye Relief
  - Image Reflections
- Nighttime/NVG Compatibility
  - Eye Relief w/NVG

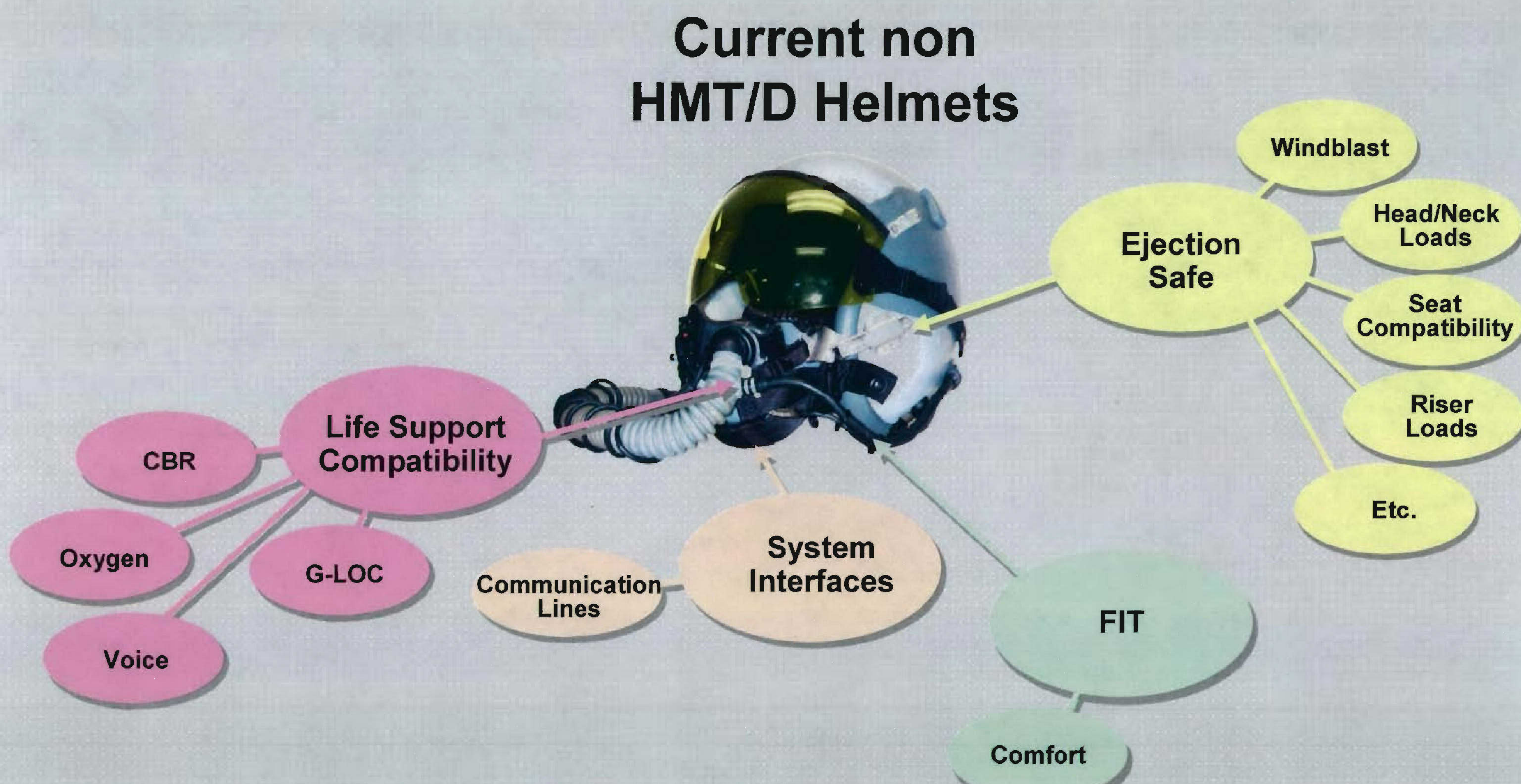
Design and Integration Issues of Visually Coupled Systems

- Tracker Characteristics
  - General Performance Requirements
  - Types of Trackers
  - Accuracy Required vs Available
  - Accuracy Types
  - Accuracy – Canopy Distortion
- Situation Awareness Presentations
  - Symbology vs. Imagery
  - Display Brightness & Imagery
  - Use of Colors

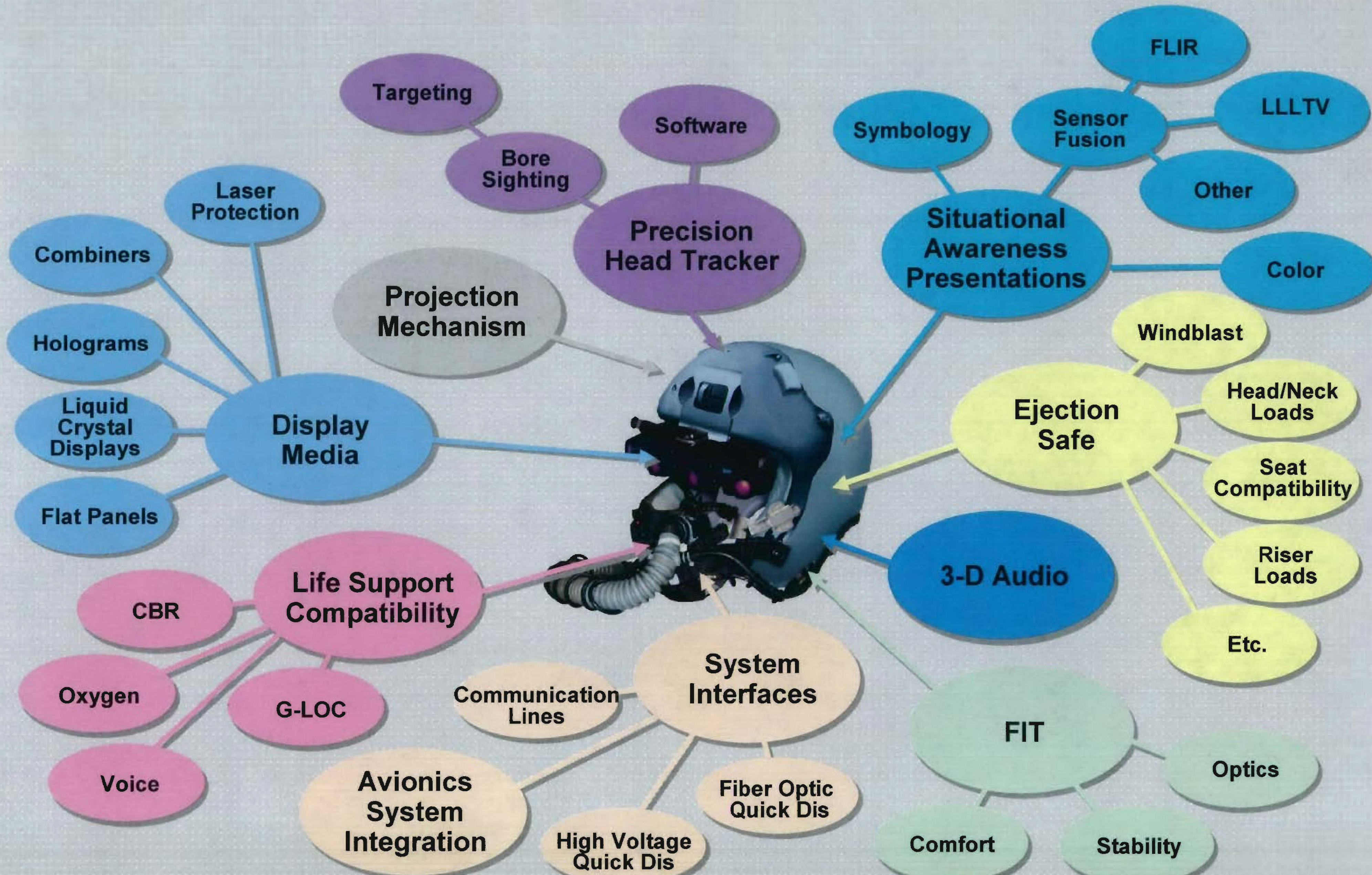
Design and Integration Issues of Visually Coupled Systems

- Physical Considerations
  - Helmet
  - Human Vehicle Interface (HVI)

Design & Integration Issues
Visually Coupled Systems



Design & Integration Issues
Visually Coupled Systems



HMST/VCS Challenges

Warfighter-SPO/Human Factors

1. System Safe and Compatible With Life Support Ensemble

2. Eyeball Is Critical Sensor (± Effects On SA Must Be Balanced)

3. System Must Be Maintainable

4. True Day, Night, & In-Weather Capability Needed

5. System Limitations Do Not Interfere With Employment (Noise, Jitter, G-A/C Motion Effects, Latency)

6. Symbology Placement Accuracy Must Suit Task

7. Display of Video Needed For Some Applications

Enhance Pilot-Defined SA

Affordable
Producible
Maintainable

Technical

1. Bulk & Weight Minimized Comfortable System, Good CG

2. Better Helmet Transparencies

3. Optimized Image Source

4. More Accurate Head Tracking Cockpit Disturbances Immunity

5. High System Update Rate Supports Useable Head Filters

6. Cable Shielding/Conduits Maintain Bandwidth Without Degrading Pilot Motion

7. Cables/Connectors Surpass Mil STD 38999, Self-Characterization

8. Advanced Symbology Supports Off-Axis SA and Quick SA Update

Display Characteristics

- Display Characteristics
  - Brightness
  - Resolution
  - Field of View (FOV)
  - Acuity
  - Color vs. Monochrome

Display Characteristics
Brightness

- **Luminance – formal definition**
  - "For most display purposes, this is the importance measurement. It is the amount of light per unit area reflected from or emitted by a surface. Although this measurement is frequently called brightness, strictly speaking, brightness is the resulting subjective sensation and is influenced by contrast, adaptation, and other factors besides the physical energy in the stimulus. Luminance is commonly expressed by a variety of units for which conversions factors are given…." [1]
  - "The amount of visually effective light emitted by an extended source. Typically expressed in footlamberts (fL) or candelas per square meter (cd/m2).

    1 fL = 3.43 cd/m2

    1 cd/m2 = 0.292 fL

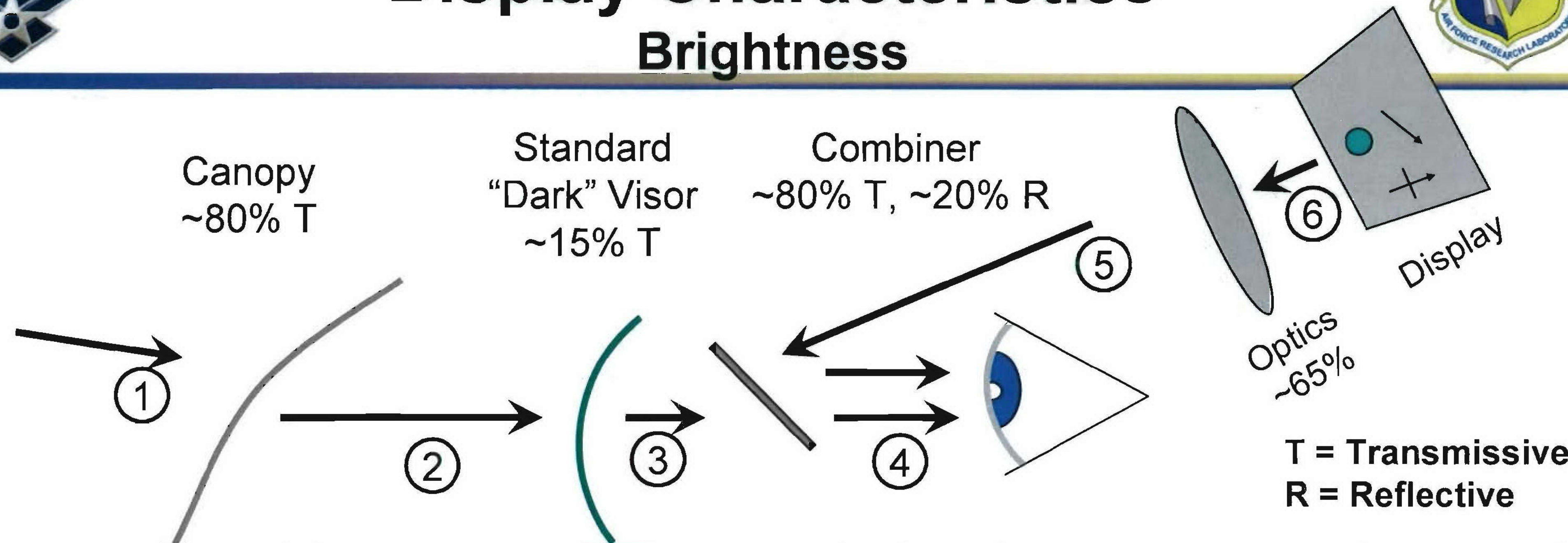
    Although often used interchangeably with brightness, luminance is a photometric standard, whereas brightness is a perceptual judgment."[2]

- **Brightness– formal definition**
  - "The attribute of a visual sensation by which a stimulus appears more or less intense or appears to emit more or less light. Although frequently used interchangeably with luminance, brightness is not a photometric standard and should not be used in conjunction with photometric units such as footlamberts. "[2]

Display Characteristics
Brightness

- Brightness – working definition
  - How much light comes from the HMD
  - The displayed information (symbology, imagery) has to be bright enough to "contend with" or "overcome" the background in order for you to be able to easily see it, recognize it, and use it.

Display Characteristics
Brightness



View	Source (13,000 FL)	After Canopy	After Visor	After Combiner	From Display[1,2]	After Display Optics	After Combiner
	Path from outside world				Path from Display		
		80% T	15% T	80% T		65% T	20% R
Path	1	2	3	4	6	5	4
Sky	10,000	8,000	1,200	960	7,385	4,800	960
Forest (20%)	2,600	2,080	312	250	1,920	1,250	250
Dry Sand (30%)	3,900	3,120	468	374	2,880	1,872	374

Notes 1: Does not account for reflections, losses etc, from display to optics.

2: Minimum display brightness to even see any symbology/image but will not be useful.

Display Characteristics
Resolution

- **Resolution – formal definition**
  - "A measure of display or image quality involving the number of displayed or resolvable elements per unit visual angle. The resolution of an electronic display may be expressed as spot size, pixel size, line width, trace width, number of television lines, and MTF."[2]

Display Characteristics
Resolution

- **Resolution – working definition**
  - **Number of discrete points in a display usually specified as number of pixels in each of the horizontal and vertical directions.**
    - Common resolutions for displays

Common name and resolution	Some Sources for Miniature Displays
– **VGA** - 640 X 480	
– **SVGA** - 800 X 600	eMagin AMOLED, Kopin LCD
– **XGA** - 1024 X 768	Kopin LCD (available ????)
– **QVGA** - 1280 X 960	Kopin LCD (available ????)
– **SXGA+** - 1400 X 1050	
– **UXGA** - 1600 X 1200	
– **QXGA** - 2048 X 1536	
– **QSXGA+** - 2800 X 2100	
– **QUXGA** - 3200 X 2400	

    - There may be other vendors with available displays
    - There are several display vendors working higher resolution miniature displays but these are not available yet.

Display Characteristics
Field of View (FOV)

- **Field of View (FOV) – formal definition**
  - "The angular extent of a display or aperture, usually expressed in degrees of visual angle and given in terms of a diameter, a diagonal, or in horizontal and vertical dimension. The corresponding clinical term is visual field and involves a mapping of the perimeter of visibility of the eyes." [2]

Display Characteristics
Field of View (FOV)

- **Field of View – working definition**
  - **The view that the display subtends.**
    - 17” LCD Desktop monitor at “normal” viewing distance (~20”), diagonally subtends ~40° (698.1 mrad).
    - VCATS has 20° FOV (349.1 mrad)
    - The Larger FOV desired means
      - Larger display
      - Larger optics
      - More pixels to retain acuity
      - Or some/all combination

Display Characteristics
Visual Acuity

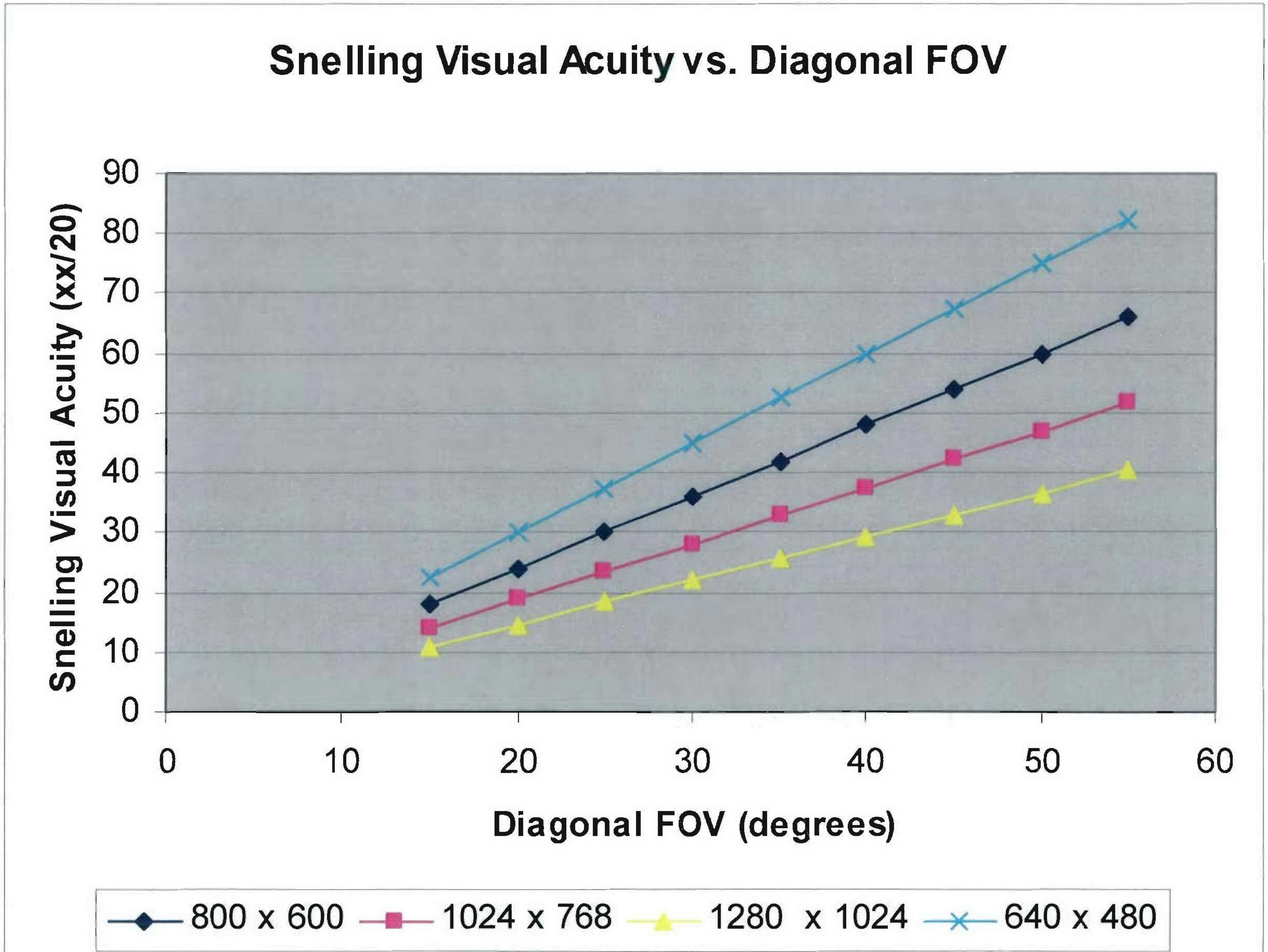
- **Acuity – formal definition**
  - "The ability to see detail in high-contrast patterns. Acuity may be expressed in minutes of arc visual angle of a target's critical detail, or as referenced to a 1-minute critical detail at 20 feet. For example, 20/20 indicates that a 5-minute target with a 1-minute critical detail (acuity targets are typically five times the size of the critical detail) can be resolved at 20 feet, 20/40 that the target needs to be 2 minutes for successful resolution, 20/80 that the target needs to be 4 minutes, etc. Normal acuity is considered to be 20/20. Displays, including HMDs are, sometimes descried as having an acuity of 20/40 or 20/60. This may mean that the detail of a 20/40 or 20/60 character can be seen on the display, but probably means that eh angular subtense of a single display pixel or element corresponds to the critical detail for a 20/40 or 20/60 character (2 and 3 arc minutes, respectively)." [2]

Display Characteristics

Visual Acuity

- **Acuity – working definition**
  - **Ability to resolve detail and is affected by luminance of scene and hence contrast ratio**
    - Common 20/20 acuity is called Snelling Visual Acuity
    - 20/20 = 30 cycles / degree or 1.72 cycles / mrad
    - 1 cycle = a bright line (or spot) followed by a dark line (or spot)
    - On pixel displays this would be a line of pixels on then a line of pixels off. (or individual pixel)
    - On 17" LCD Desktop Monitor with 1280 x 1024 pixels viewed at 20" (40° FOV) = 20.5 cy/° or ~29.3/20 Snelling Visual Acuity
    - For 20° x 30° FOV with 800 x 600 resolution > 13.87 cy/° ~43.3/20 Snelling Visual Acuity
    - Can (will) be affected by optics system

Display Characteristics
Visual Acuity



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Display Characteristics
Size & FOV

- Depending on:

Display Type	LCD, AMOLED, Scanning, Ferroelectric Liquid Crystal (FLC)
If color, method	Sequential, RGB Pixels
If color & RGB pixels	Linear pattern, tri pattern, quad pattern
Pixel Aspect ratio	Square, rectangular
Resolution	

Then Display Size is generally proportional to number of pixels. The more pixels, the larger the display, the larger the optics, the greater the weight and the more power required to run.

Visor / Combiner

- Visor / Combiner
  - Standard vs. Custom Visor
  - Visor Projected Vs. Combiner Projected
  - Image Pre-distortion
  - Eye Relief
  - Image Reflections

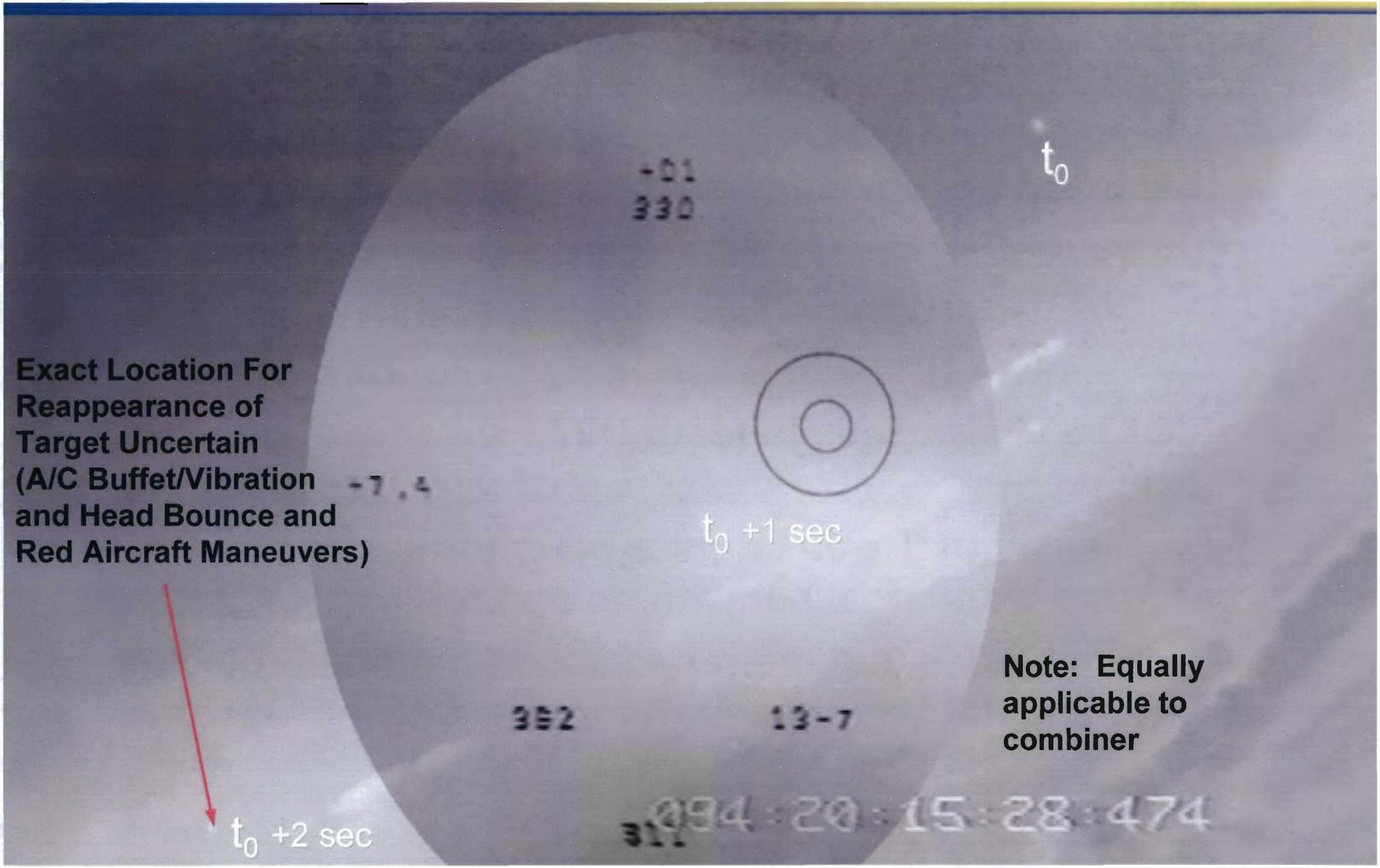
Visor / Combiner

Standard vs. Custom

- Standard USAF Visor is Toroid shape, i.e. a section of "skin" cut-off of a donut.
- Standard USAF Visor transparencies;
  - Neutral – 15% - 18% transmissive ("Day" visor)
  - Clear – 90% transmissive (clear night visor)
  - Yellow – 70% transmissive (high contrast visor)
- VCATS visor used standard USAF visor with no patch
  - Display CRT was brighter permitting projection onto standard visor with no patch
  - Patch adds darker area to accommodate projected image not bright enough for "un-patched" visor

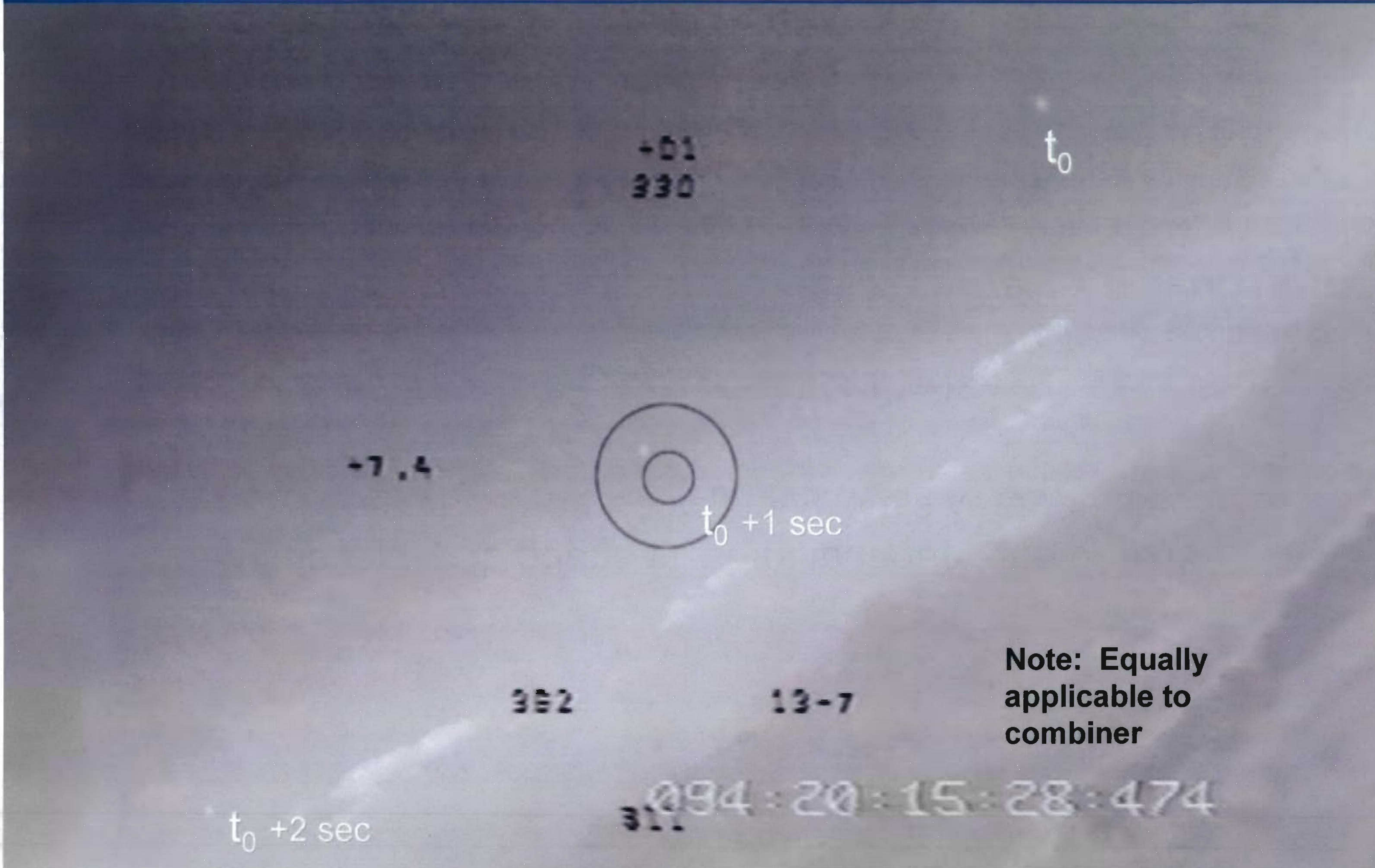
Visor / Combiner

Helmet Visor With Reflective Patch



Visor / Combiner

Helmet Visor With NO Reflective Patch



Note: Equally applicable to combiner

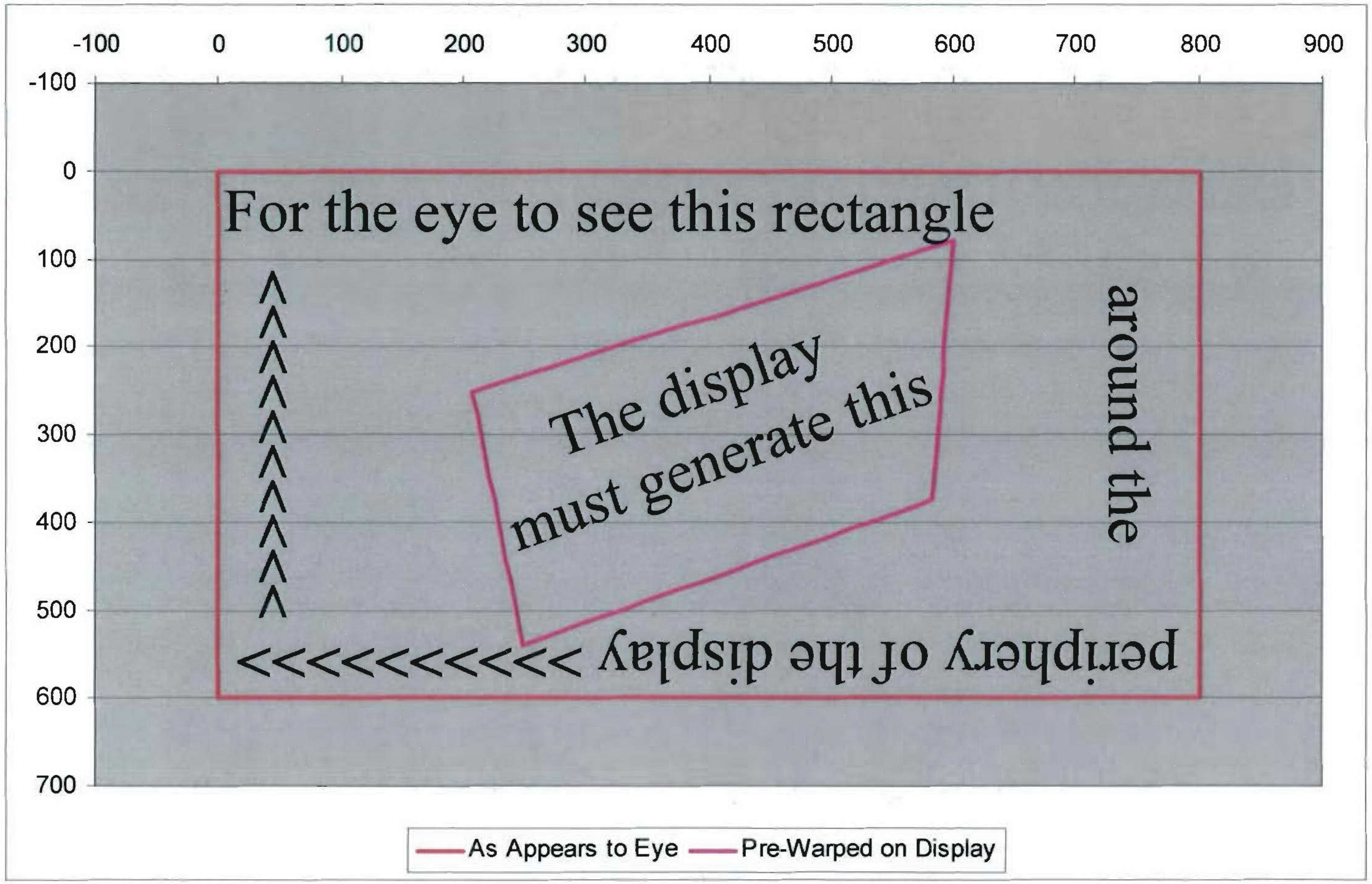
Visor / Combiner

Visor vs. Combiner

	Visor	Visor w/Patch	Combiner
Eye Relief	Greater	Greater	Less
Visor Stability Requirement	Required	Required	Not Required
Potential for eye injury during ejection	Not Affected	Not Affected	Increased
NVG Compatible	No	No	Possibly
Effect on visual acuity	Some degradation	More degradation	More degradation

- Combiner may simplify optics and pre-warping requirements depending on its shape and placement of display source

Visor / Combiner
Image Pre-warping

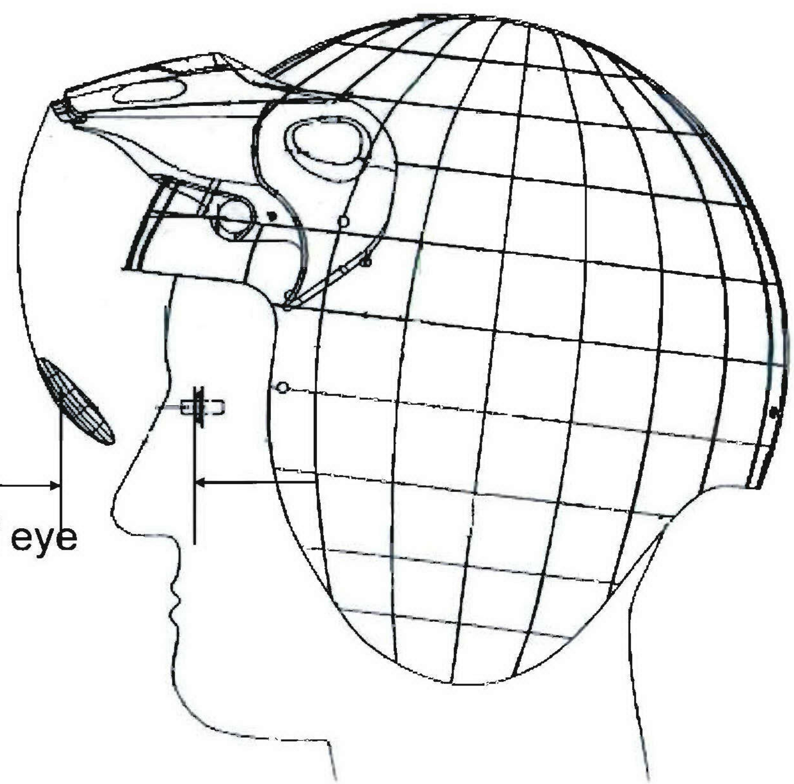


VCATS Warping

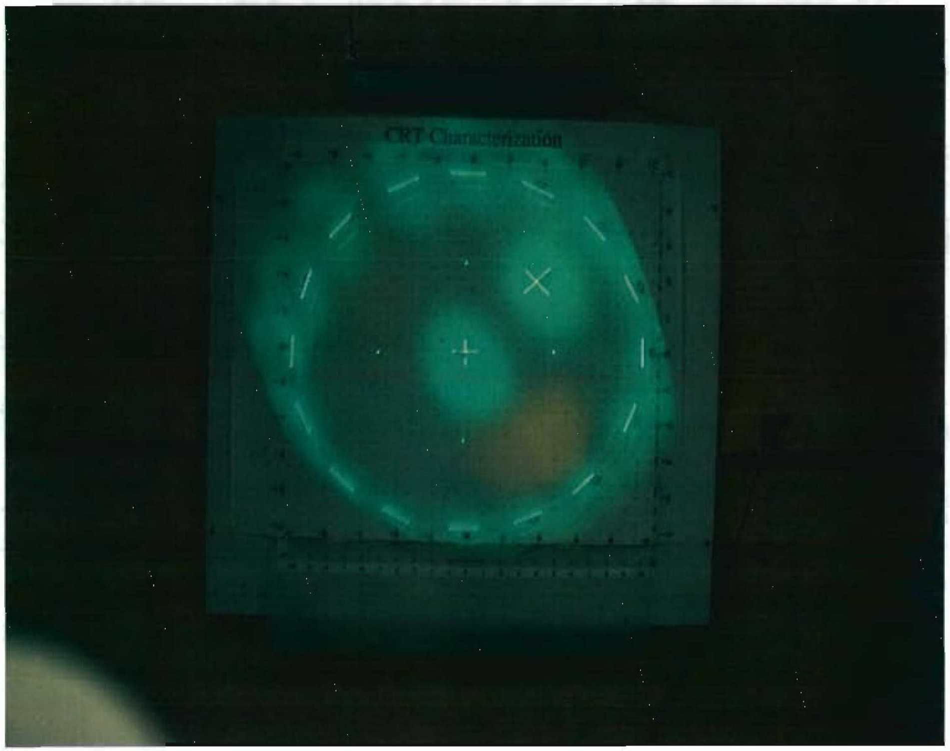
The VCATS optics system was optimized for a CRT, not a flat panel (LCD or OLED) display, one reason for the large area of "wasted" pixels above. This is one reason why we could not simply substitute a new flat panel display in the CRT based VCATS system without redesigning the optics.

Visor / Combiner
Eye Relief

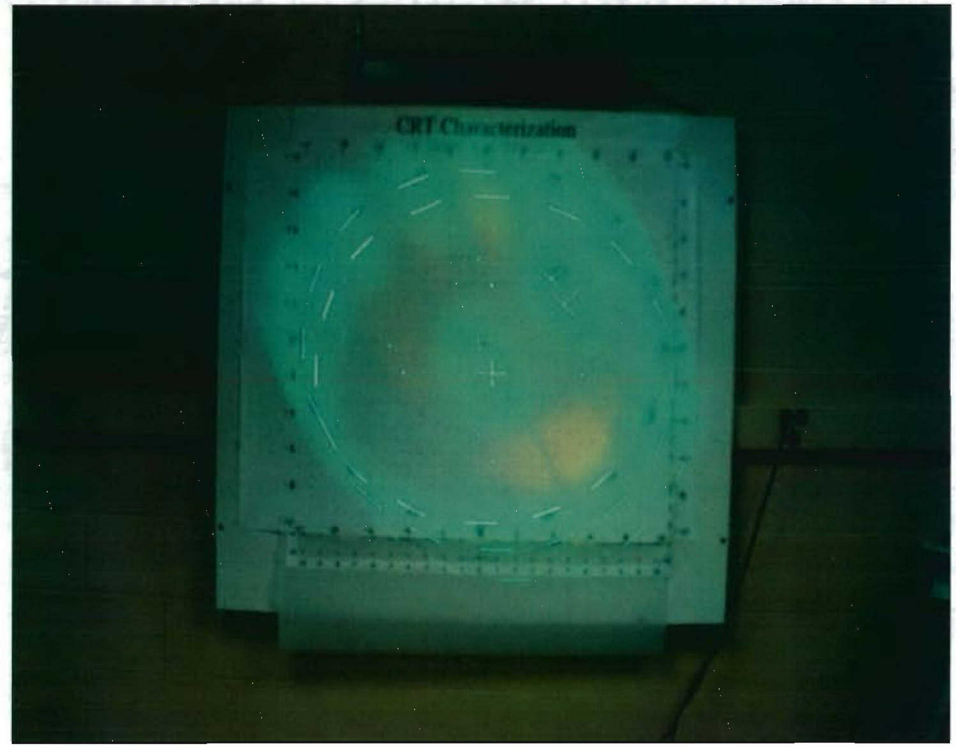
- Eye Relief – working definition
  - Distance from last optical element surface to the cornea



Visor / Combiner
Image Reflections



VCATS Display with 25% visor, max brightness. Note blooming around symbols as a result of brightness set much higher than needed for room environment, but may be needed for daytime flight.



VCATS Display with one prototype version of LEP visor, again, max brightness. Note blooming around symbols as a result of brightness set much higher than needed for environment, but also note multiple images due to reflection off multiple surfaces.

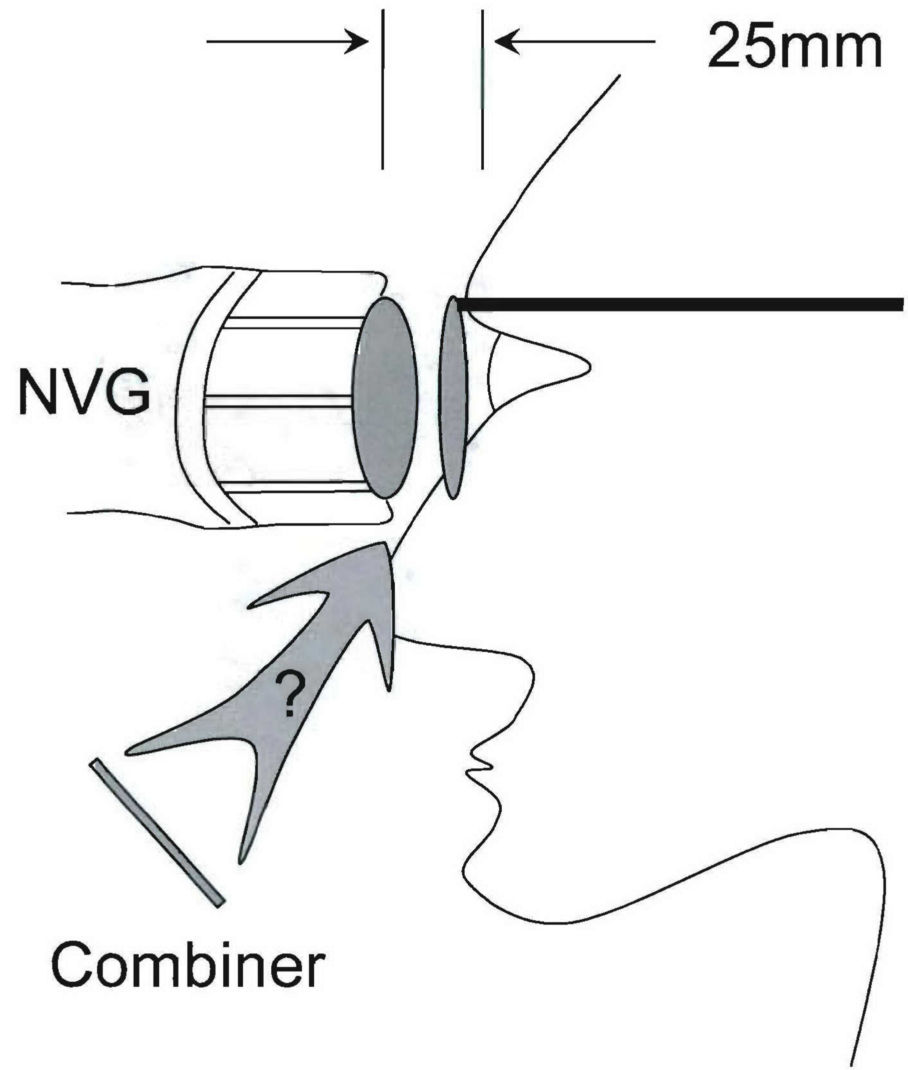
Night Vision Compatibility

- Nighttime/NVG Compatibility
  - Eye Relief w/NVG

Night Vision Compatibility

Eye Relief w/NVG

	Eye Relief
Std Spectacles	12.5 mm typical Lens ~3mm
NVG (4949)[1] for full FOV	25mm to accommodate spectacles
Eye Respirator	



Notes:
1 – As eye relief increases, FOV decreases

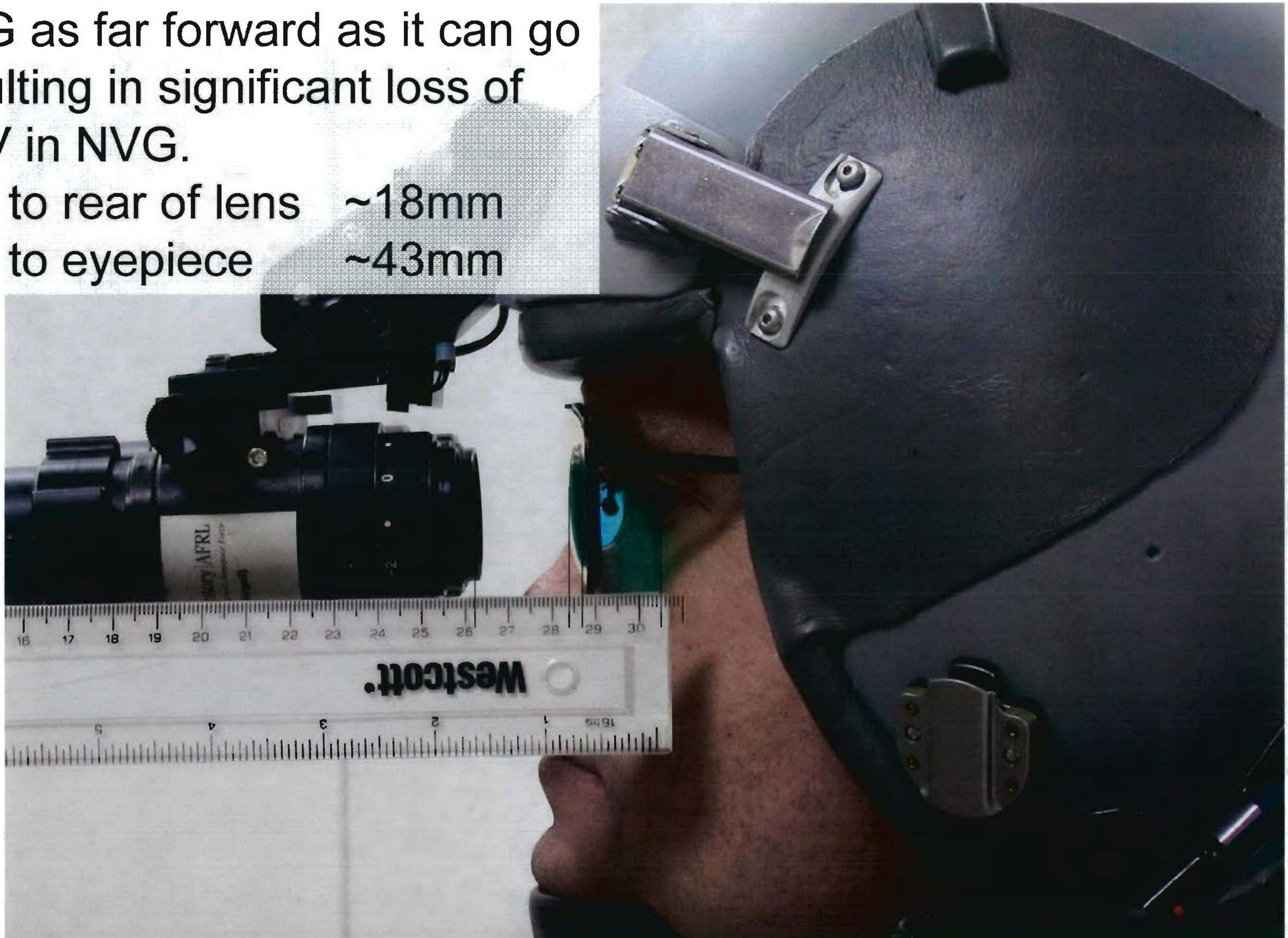
Eye Relief – distance from surface of last optical element to surface of the cornea

Night Vision Compatibility
Eye Relief w/NVG

NVG as far forward as it can go resulting in significant loss of FOV in NVG.

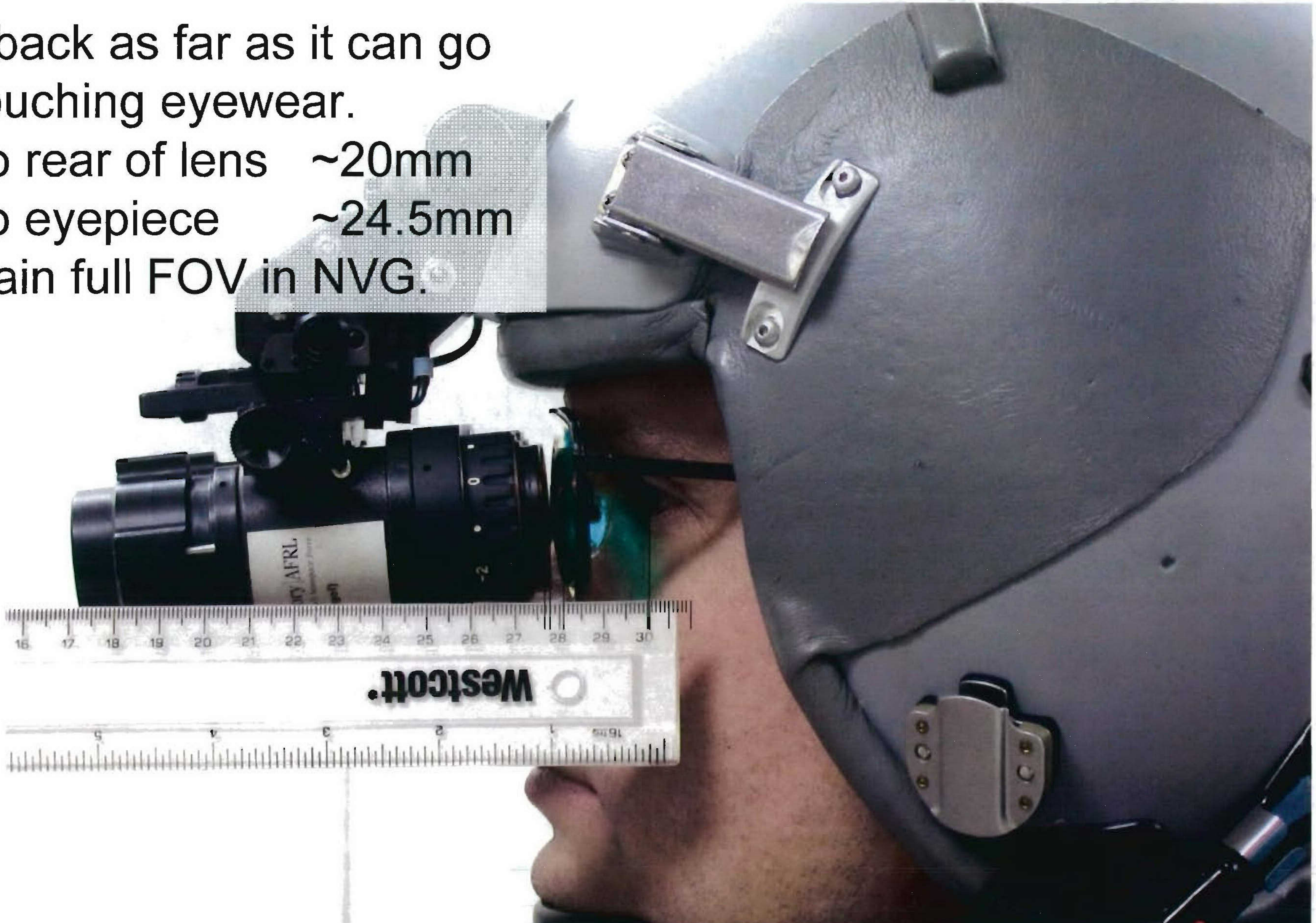
Eye to rear of lens ~18mm

Eye to eyepiece ~43mm



Night Vision Compatibility
Eye Relief w/NVG

NVG back as far as it can go
w/o touching eyewear.
Eye to rear of lens ~20mm
Eye to eyepiece ~24.5mm
Maintain full FOV in NVG.



Helmet-Mounted Tracker

- Tracker Characteristics
  - General Performance Requirements
  - Types of Trackers
  - Accuracy Required vs. Available
  - Accuracy Types
  - Accuracy – Canopy Distortion

Tracker Characteristics

General Performance Requirements

- Head Rates
  - Head Angular Velocity Rates In A/C Can Reach 400 Deg/Sec
  - Head Acceleration In A/C Can Reach 1000-2000 Deg/Sec^2 ?
- Helmet Position & Orientation (P&O) Needed For HUD, Windscreen, and Canopy Correction Algorithms
- Transducer Technology/P&O Algorithms Must Handle All Environmental Disturbances With Predictable Results

Tracker Characteristics

General Performance Requirements (cont.)

- Update Rate of 1-2000 Per Sec Needed For Effective Multi-pole Digital Filters That Produce Low Phase Error For:
  - HUD
  - HUD-Replacement With Space-Stabilized Symbology On HMD, and
  - Biodynamic Interference Suppression During High-G Buffet & Vibration

- Lag/Latency
  - Latency – time interval between samples
  - Lag – "Age" of information.

Tracker Characteristics
Types of Trackers

- Magnetic
  - Magnetic transmitter in cockpit generates a magnetic field generally sequentially in 3 axis. A magnetic receiver on the helmet senses the field and the electronics unit derives position and orientation.
  - Pros: small sensor
  - Cons: sensitive to magnetic disturbances in cockpit, I.e. magnetically conductive objects, etc.
- Optical
  - Several optical emitters, usually on helmet emits energy and optical sensors, usually referred to as cameras, sense the optical emission and the electronic unit calculates position and orientation.

Tracker Characteristics
Types of Trackers

- Inertial
  - Uses miniature accelerometers and rate sensors on helmet that sense head accelerations. Electronics unit processed data to derive line of sight vector and sometimes position in cockpit
  - Needs inertial information from aircraft since its motion will affect head-mounted sensors as well. The aircraft accelerations and rotations must be removed from the head measured values.
  - Pros: can be fast
  - Cons: needs a/c inertial info
inertial sensor drift needs correction
- Ultrasonic
  - Ultrasonic transducers measure distance between sender and receiver. With a number of emitters and receivers, can triangulate position and derive orientation.
  - Pros: simple
  - Cons: Slow
speed of sound varies with temperature, corrections needed

Tracker Characteristics
Types of Trackers

- Hybrid (combination of types)
  - Inertial/ultrasonic
  - Inertial/magnetic

Tracker Characteristics

Accuracy Required vs. Available

- Tracker Accuracy – the degree to how well the tracker system determines the line-of-sight (LOS) vector and/or the position in the cockpit with respect to a reference.
  - LOS Vector – often referenced to the same reference frame used by the weapon system on the aircraft. (Along the centerline, level with the waterline, and along the cross product of the two).
  - Position – used along with LOS vector for canopy corrections and if HUD substitution is attempted or some type of virtual instrument panel is being attempted.

Tracker Characteristics

Accuracy Types

- **Accuracy**
  - **Types**
    - Laboratory – static or dynamic
      - Lab Static – usually the best possible accuracy obtainable by a tracker system and is often the accuracy cited by the manufacturer
      - Lab Dynamic – usually not a good as lab static but better than an installed accuracy. Often difficult to simulate all dynamic conditions associated with flight but provides a more realistic representation of system performance.

Tracker Characteristics
Accuracy Types

- **Accuracy**
  - **Types**
    - Installed – static or dynamic
      - Installed Static – More difficult to measure. Depending on system requirements for calibration, boresighting etc, is more difficult to measure. Various attempts have been made to measure using pilot sitting in the seat sighting stars, sighting known targets in a hanger, or similar varying degrees of success.
      - Installed Dynamic – not been attempted since it is very difficult to measure the true position/orientation to compare tracker determined position/orientation.

Tracker Characteristics

Accuracy Types

- **Accuracy**
  - **Types**
    - Operational – static or dynamic
      - Operational Static – Most difficult to measure. Significant problems determining "truth" that can be used to quantify tracker performance. Efforts are under way to do this with instrumentation pods and data recorders on the Eglin range.
      - Operational Dynamic – not been attempted since it is very, very difficult to measure the true position/orientation to compare tracker determined position/orientation in operational environment. Usually determined as "good enough" by testers/operators when using tracker in operational scenario.

Tracker Characteristics
Accuracy Types

- **Accuracy**
  - **LOS – "Good enuf to do the job"!**
    - Air – Air weapons engagement
      - Better than ½ weapon's sensor field of view
        - When the weapon is slewing to head position, and the pilot puts the cross hairs on the target, the weapon's sensor will see the same target with sufficient energy to allow it to lock-on.
    - Air – Ground
      - Its been generally held that a tracker system (tracker coupled with aircraft installation coupled with human performance) can be made good enough to provide weapons grade coordinates. Thus the tracker system would be used to slew targeting pod or weapon sensor with sufficient accuracy so that its sensor can be used to fine tune the solution.
      - Better than 1/3 weapon's sensors field of view.
        - This is similar to requirement for air – air above, but requires additional pointing accuracy so that if an imaging sensor is being used (targeting pod video) the operator can recognize the scene in the sensor video and then fine tune the solution manually.

Tracker Characteristics

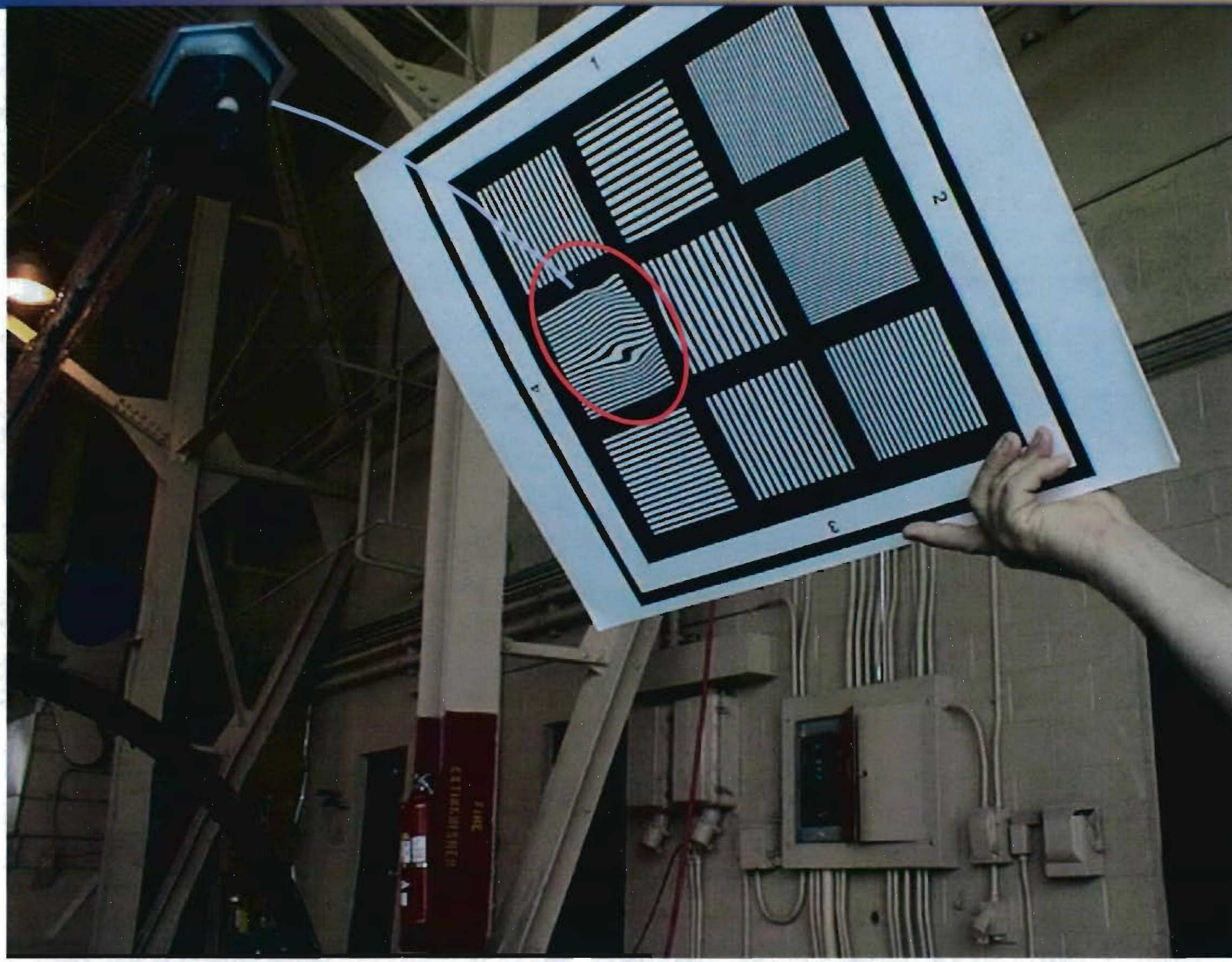
Accuracy Types

- **Accuracy – cont.**
  - **LOS – cont.**
    - Air – air & air – ground symbol placement
      - Sufficient so that symbol is positioned over the object of interest. Object identifying symbols vary in size from 6mr to 25mr depending on function.

Tracker Characteristics
Accuracy Types

- **Accuracy – cont.**
  - **Things that affect accuracy.**
    - System Installation
    - System Latency
    - System Lag
    - Calibration
    - Boresight
    - Canopy distortion
    - Flight conditions

Tracker Characteristics
Accuracy – Canopy Distortion



Looking from inside of canopy out over your left shoulder

Situation Awareness Presentations

- Situation Awareness Presentations
  - Symbology vs. Imagery
  - Display Brightness & Imagery
  - Use of Colors

Situation Awareness Presentations

Symbology vs. Imagery

- Symbology
  - Used to identify objects of interest, provide queuing mechanisms (ex. cross-hair, sensor position, sensor FOV, pointing arrow, etc.)
  - Provide information such as aircraft performance (airspeed, altitude, etc.), sensor status, target info etc.
  - Usually simple in nature, standardized in shape and meaning.
  - May use line type (solid, dashed) and/or color, if available, to further identify
  - Generally very effective

Situation Awareness Presentations
Symbology vs. Imagery

- Imagery
  - Pictures
  - Source can be from weapon/targeting sensor, vision enhancement devices such as FLIR, from either on/off board sources.
  - Video, maps, charts, photographs
  - Difficult to see and use when viewed on a see-through display. Effective use often requires a "look-at" display.
  - 1980 Agard report summarized that viewing imagery on a see through display was not advised/useful.

Situation Awareness Presentation

Viewing imagery through transparent visor/combiner

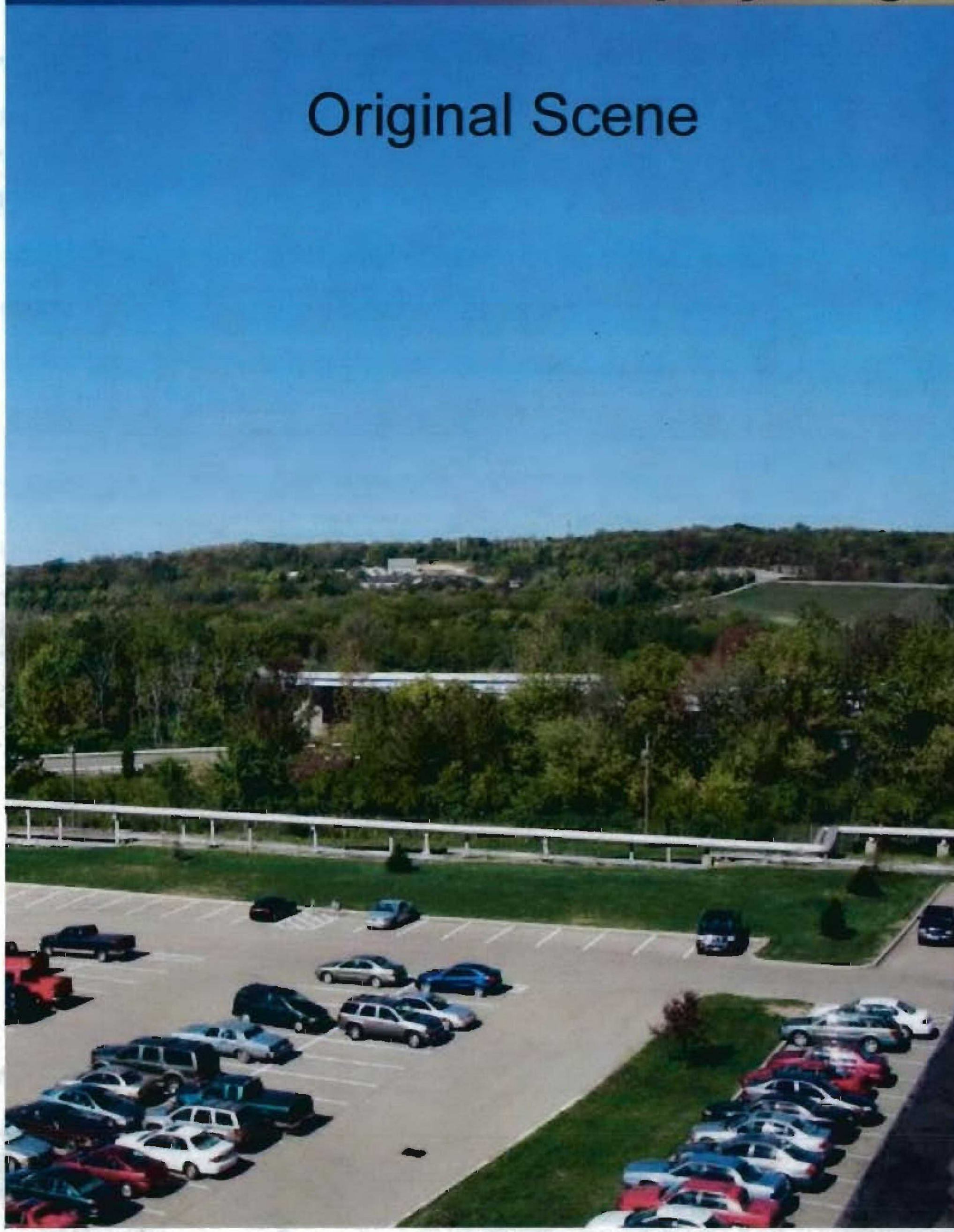
- **Brightness and display format**
  - **The next set of slides shows a build–up of images that represent what would be seen when viewing a "target" through the HMD system.**
    - Raw Scene
    - Then Scene through:
      - windscreen
      - windscreen and visor
      - windscreen, visor and combiner (wvc)
      - wvc with symbology
      - wvc with color sensor image scaled to real world
      - wvc with color sensor image enlarged approximately 4x.
      - wvc with color sensor image enlarged to fill vertical display area
      - Each of above three, but with monochrome sensor image instead of color

Situation Awareness Presentation

Display Brightness & Imagery

Situation Awareness Presentation

Display Brightness & Imagery



Situation Awareness Presentation

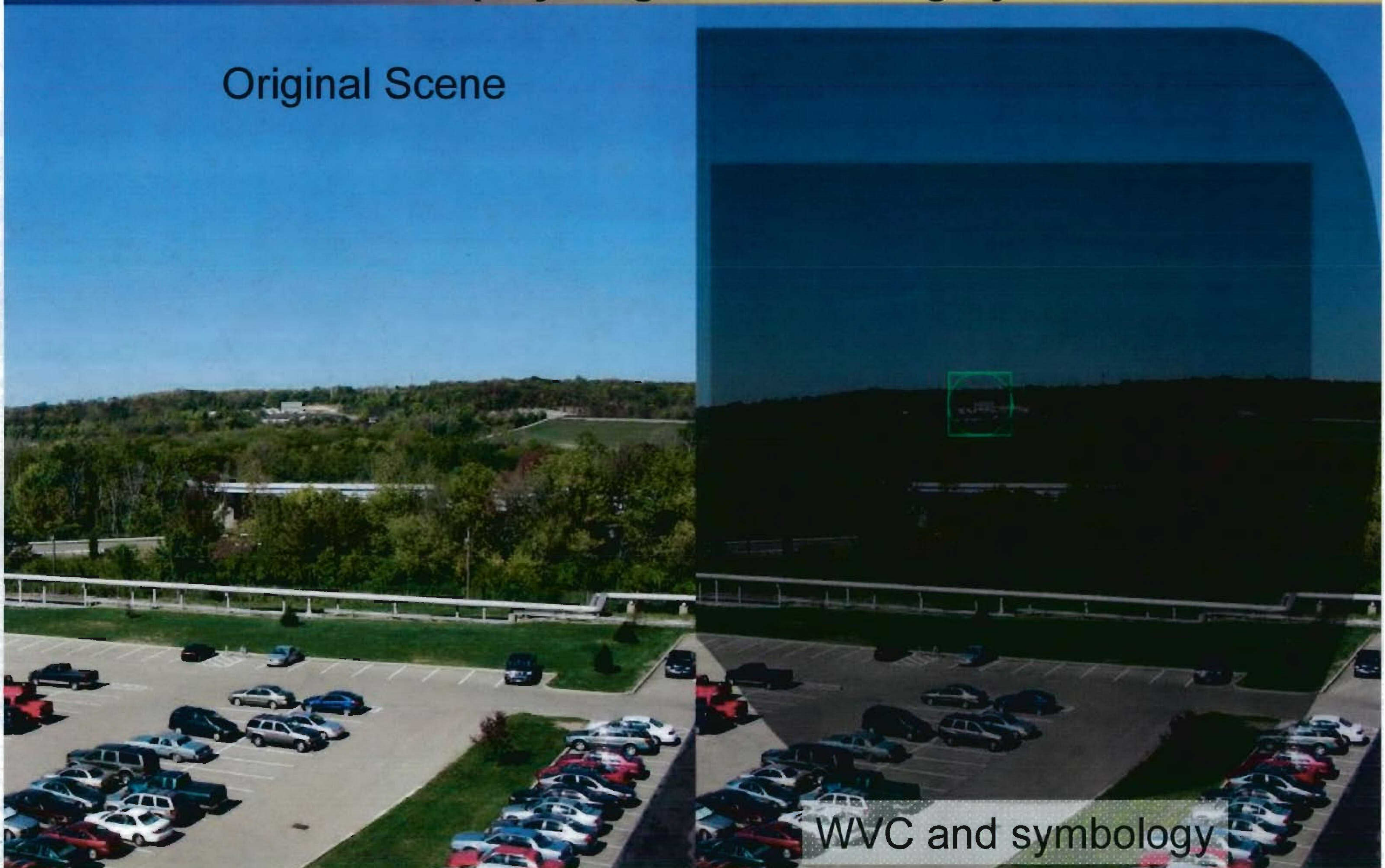
Display Brightness & Imagery

Situation Awareness Presentation

Display Brightness & Imagery

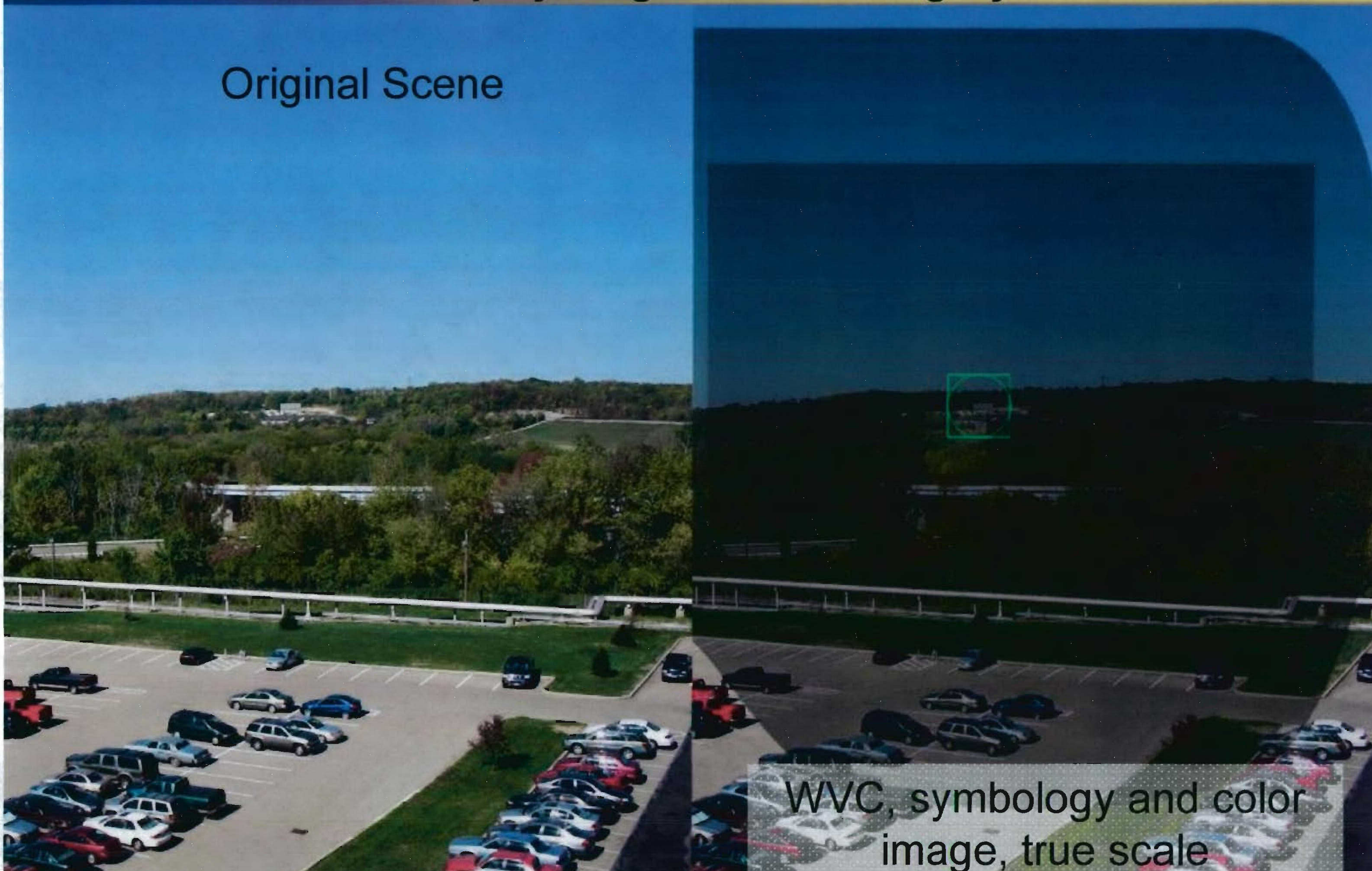
Situation Awareness Presentation

Display Brightness & Imagery



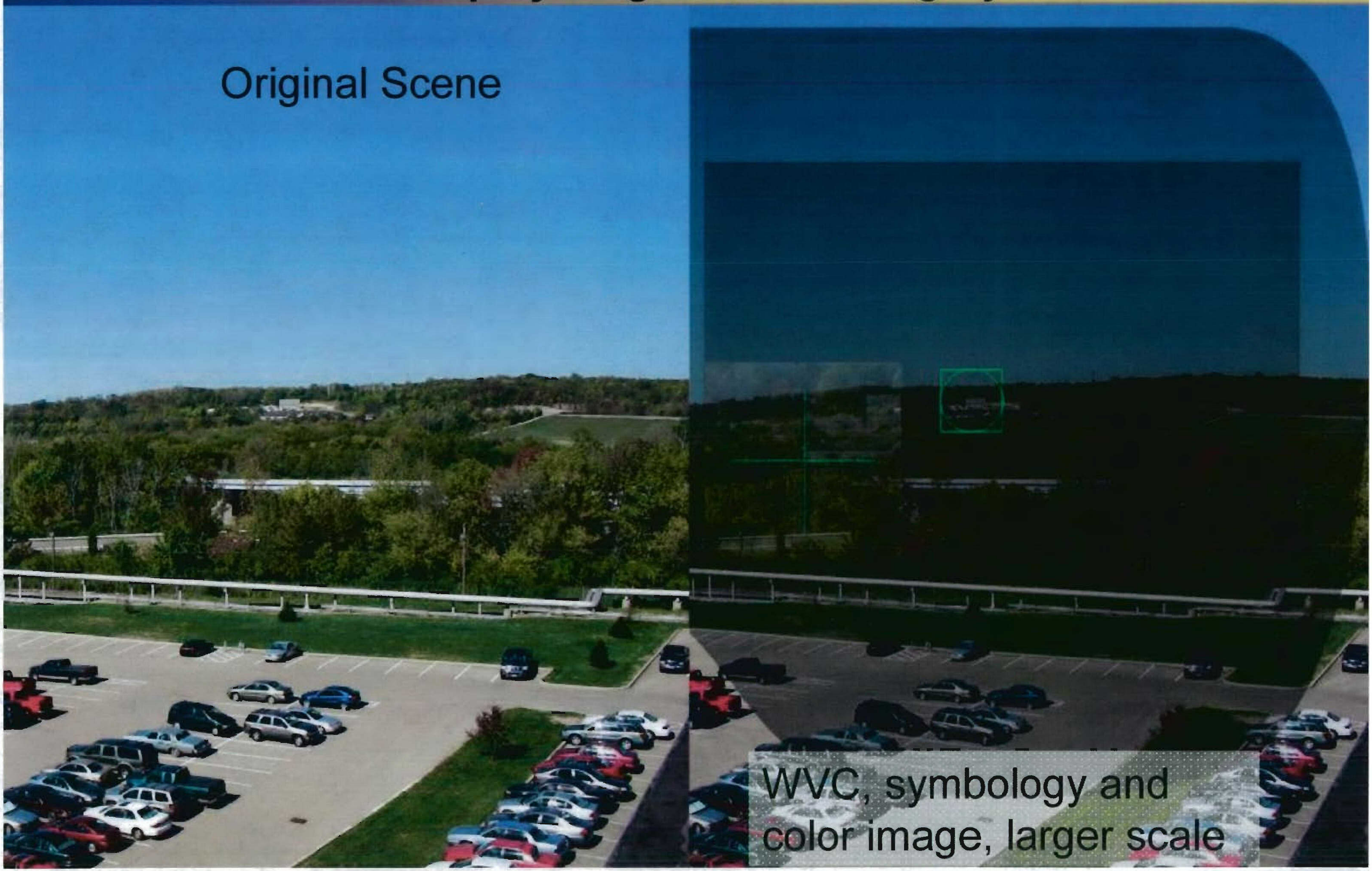
Situation Awareness Presentation

Display Brightness & Imagery



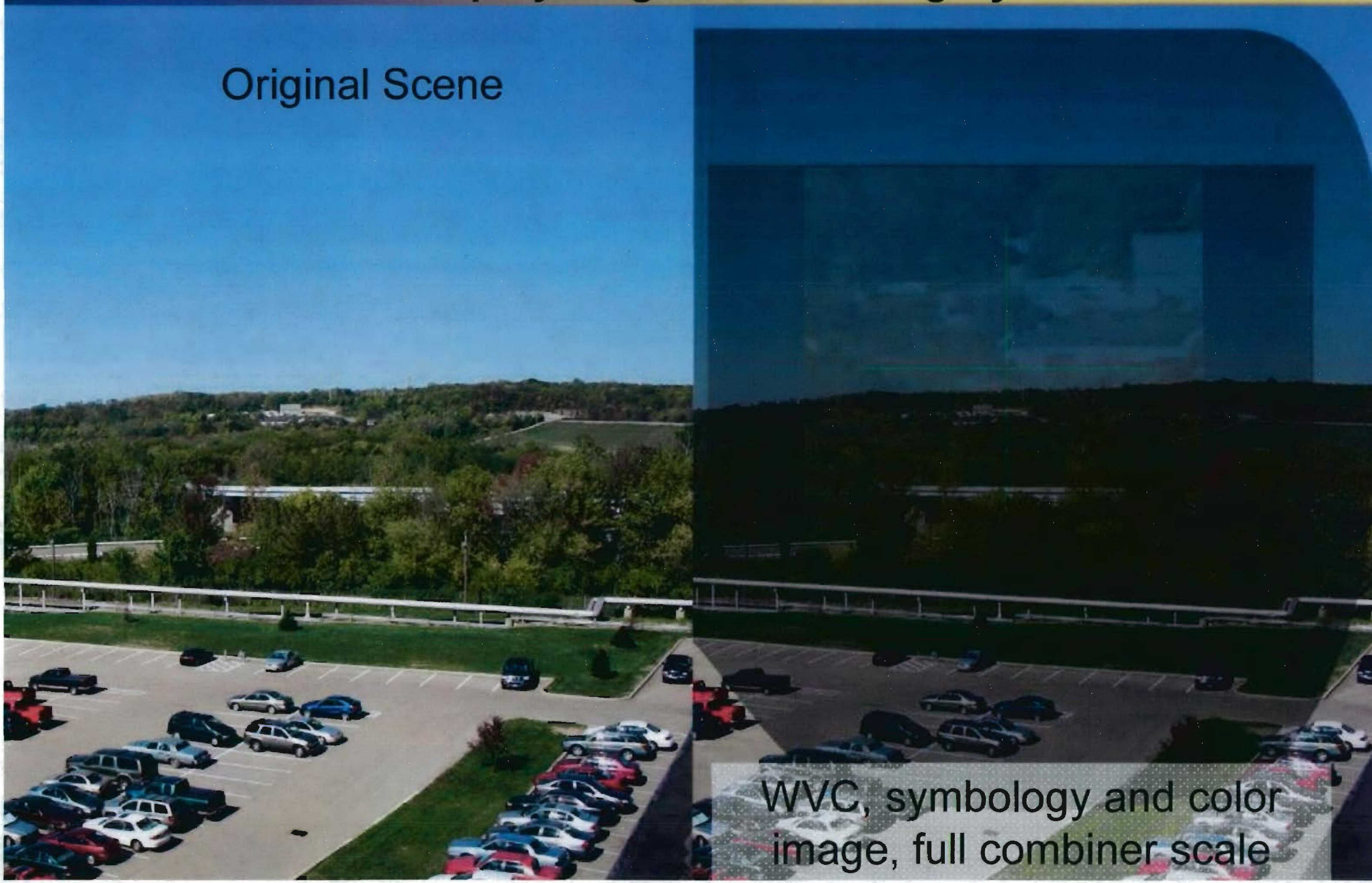
Situation Awareness Presentation

Display Brightness & Imagery



Situation Awareness Presentation

Display Brightness & Imagery



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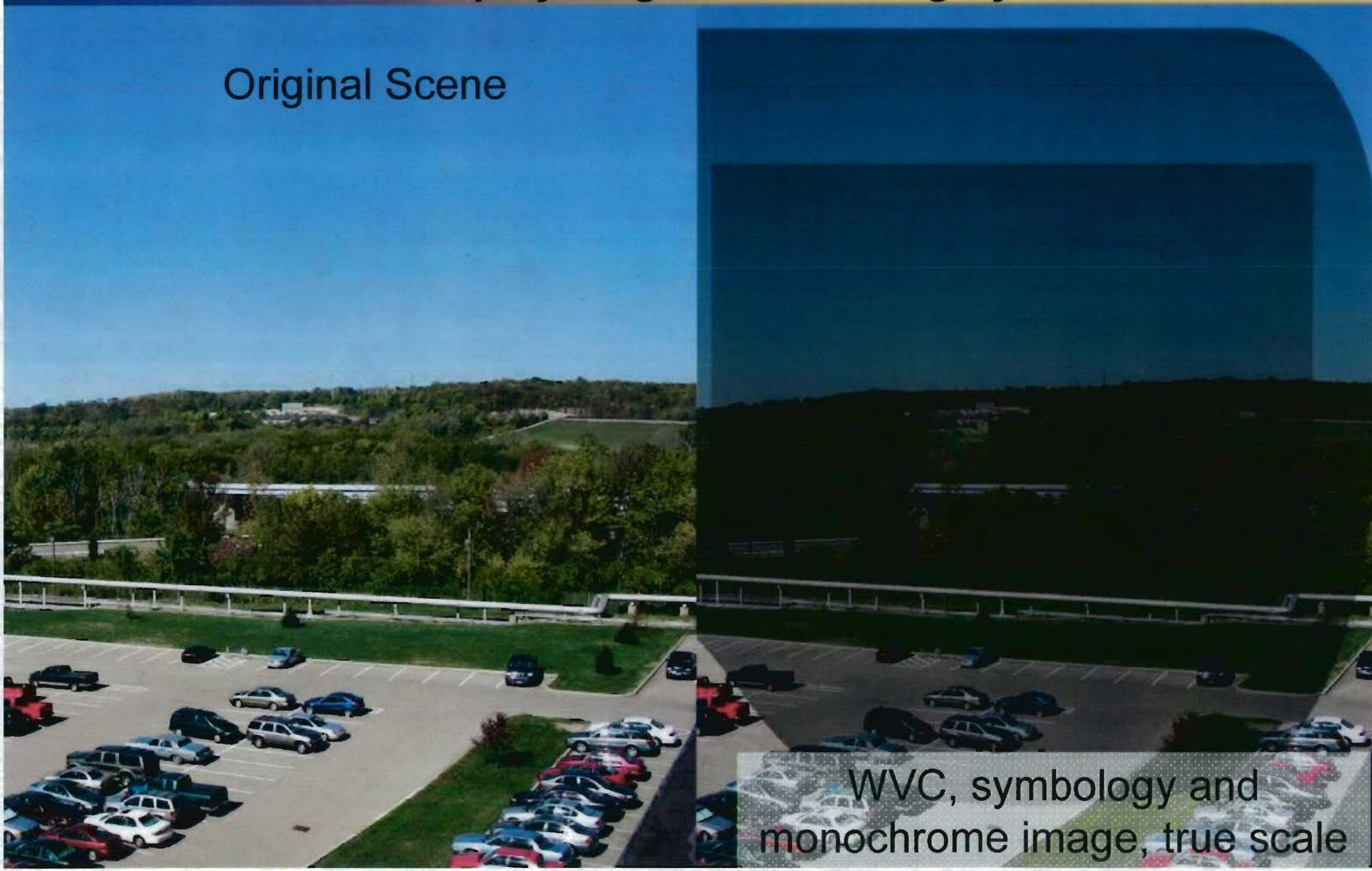

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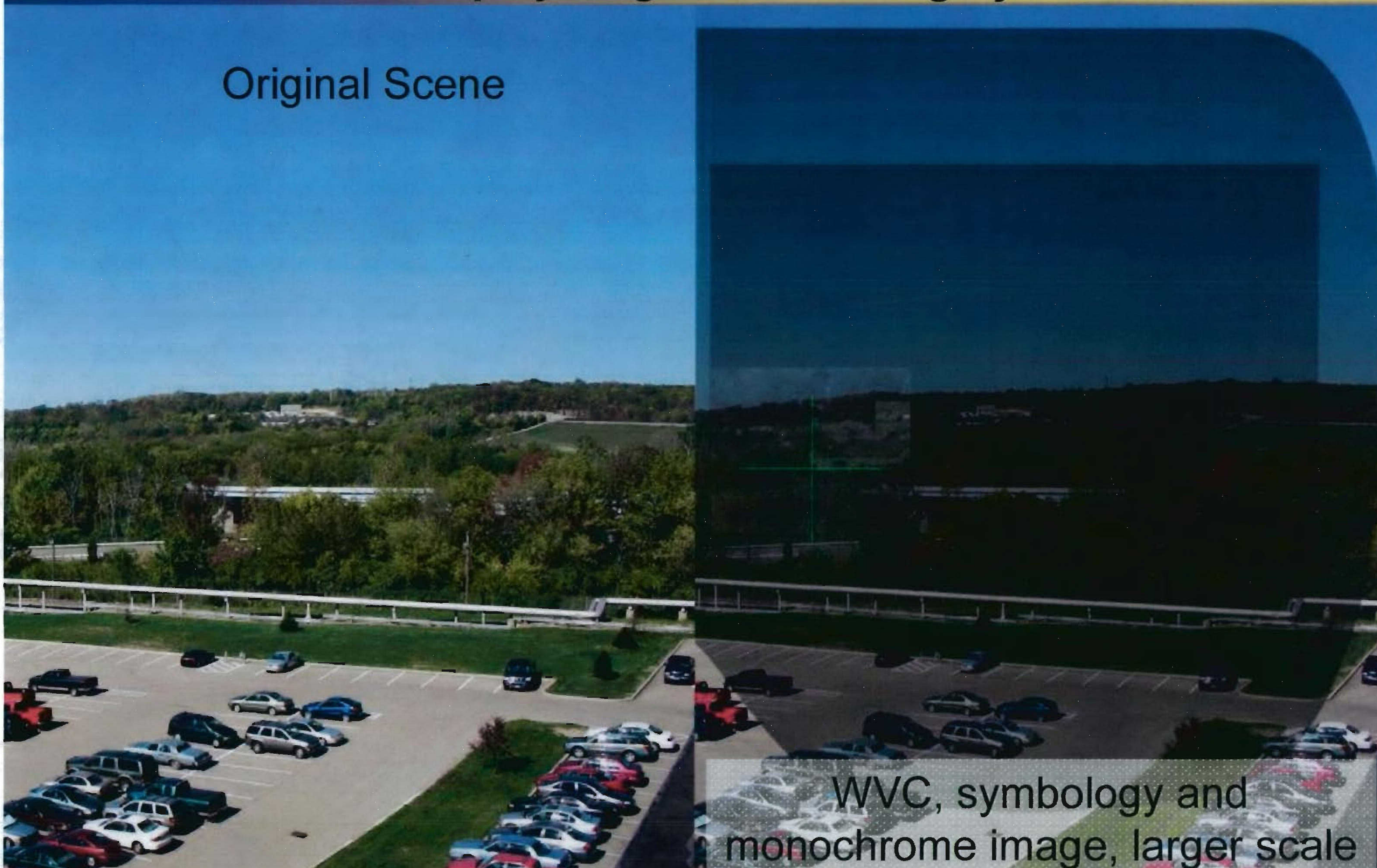
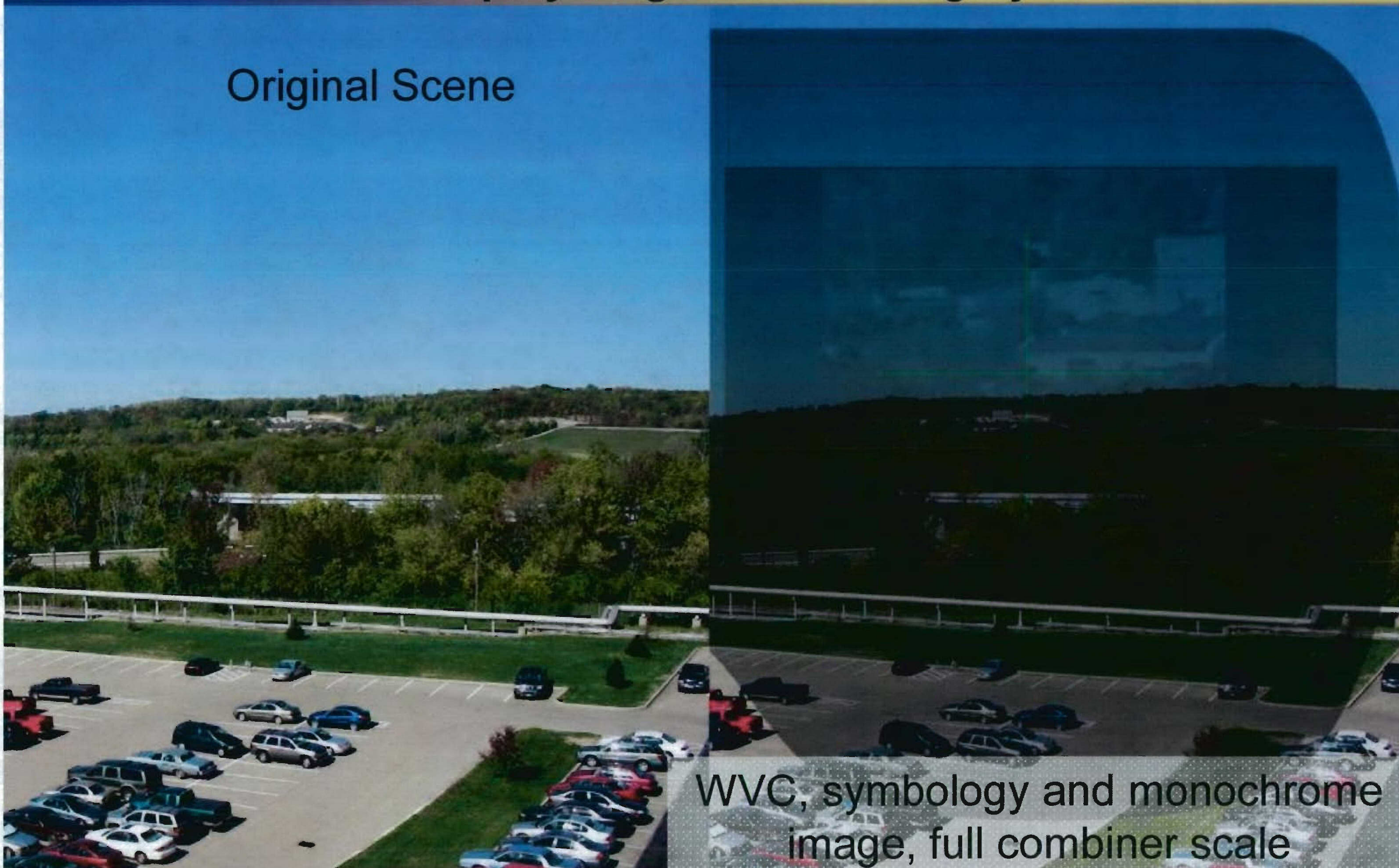


Situation Awareness Presentation

Display Brightness & Imagery



Situation Awareness Presentations

Use of Color

- **Found that color can be effective used on symbology to help in identifying information**
- **Contrast ration of 1.2:1 resulted in high probability of correctly determining color against all backgrounds.**

$$\text{contrast ratio} = \frac{l\,\text{max}}{l\,\text{min}}$$

$$l = \text{luminance}$$

Or, the luminance of the symbol over the luminance of the background.

Physical Considerations

- Physical Considerations
  - Helmet
  - Human Vehicle Interface (HVI)

Physical Considerations
Helmet

- "Standard" vs custom
- Standard is HGU-55P
- HGU-55P generally is not satisfactory "on its own." It usually needs some modifications:
- Reinforce along edges for additional support
  - Modify back end to accommodate cable entrance
  - Modify crown for removable module connector
  - May uses custom visor
  - Pros and cons
    - Pros — "Standard" modified significantly
    - Cons — Stability; Not built as a platform for HMD/T

Physical Considerations
Helmet

- **Custom**
  - **New item**
  - **Potential for two piece helmet**
    - Electronics on outer shell
    - Individual has custom comfort and protective liner
  - **Pros and Cons**
    - Pros — Built specifically for HMD/T platform; Can be very stable
    - Cons — More expensive right now until AF adopts

Physical Considerations
Helmet

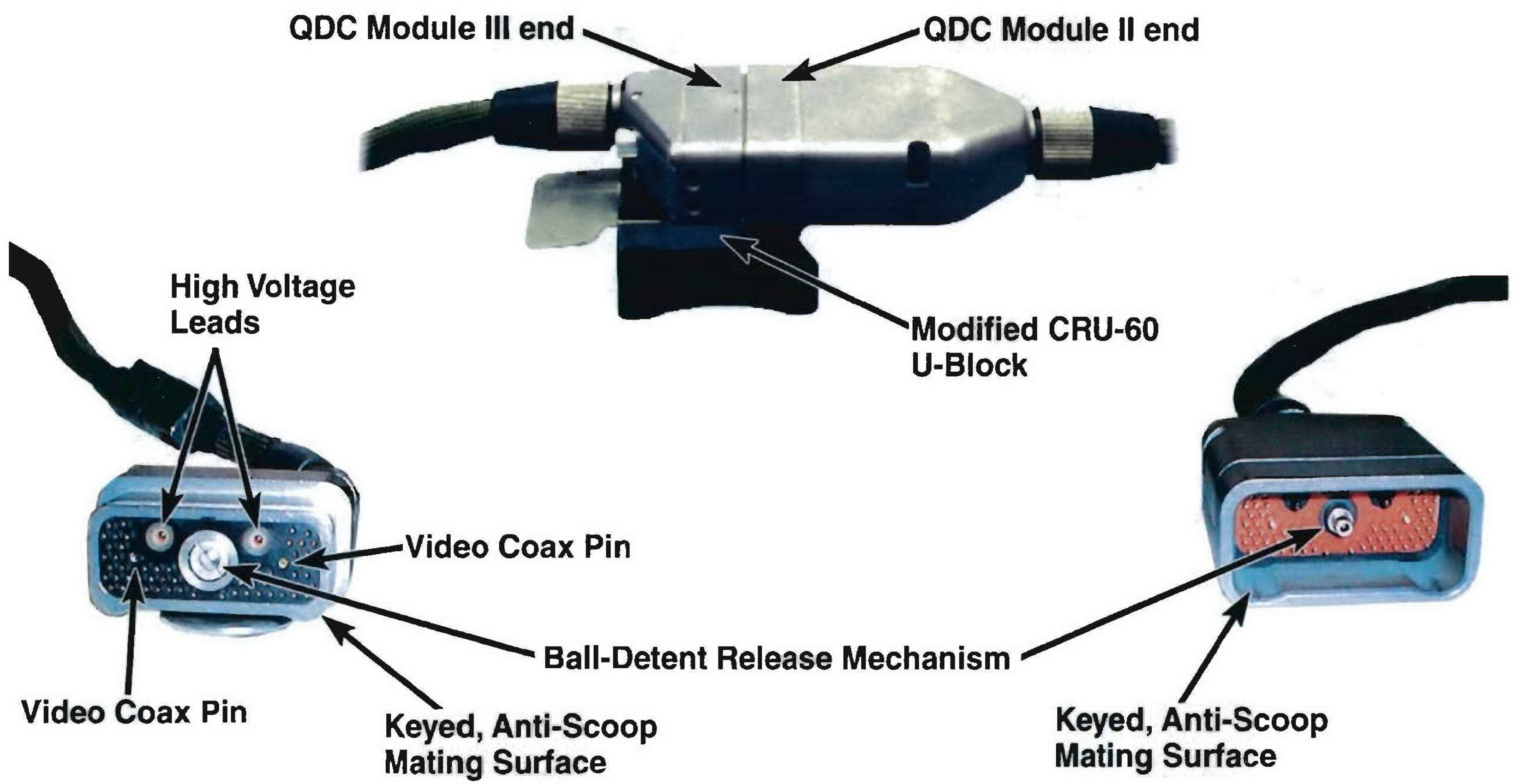
- **Other considerations**
  - **Weight**
  - **Center of gravity**
  - **Stability**
    - Affects tracker performance if it slips on head
    - Eye can move out of “eye box” or exit pupil causing displayed image to disappear
  - **Size**
    - Additions adversely affect airflow to ejection seat Pitot tubes
    - Affect head motion and add potential to bang canopy

Physical Considerations
HVI –Disconnect(s)

- Quick Disconnect (QDC)
  - Permits rapid and sure method to connect helmet system to aircraft
  - Primary method for pilot to connect system to aircraft
  - Environmental aspects
  - Ejection and Emergency Egress
  - High Voltage (if present) protection
  - Explosive atmosphere
- Helmet Release Connector (HRC)
  - Limited use
  - Protects pilot from flailing helmet should helmet come off during ejection

Physical Considerations
HVI – Quick Disconnect

Module II & III Sides of QDC
Shown Mated and Positioned in MCRU-60

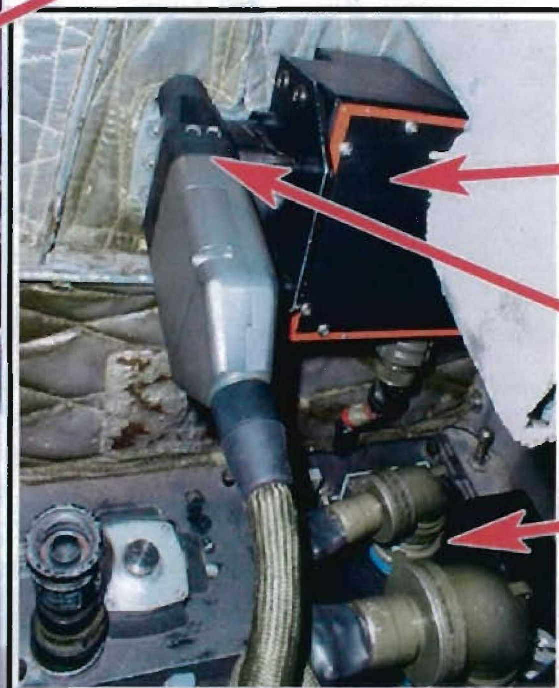


Physical Considerations
HVI – Cable & Routing

- HVI Cable
  - Highly flexible
  - Strong
  - Protected from abrasions and foreign matter (fluids, grease etc.)
- HVI Cable Routing
  - Does not interfere with existing life support/ejection items
  - Loop does not encumber head motion
- Cable/connector stowage when flying w/o HMD

Physical Considerations

HVI – Cable & Routing



- VCATS ROMA with Module V
- HGU-55/P with Module IV Flex Cable
- HVI Service Loop and Nape Strain Relief
- Helmet Release Connector (HRC)
- Integrated Parachute Harness Flue to HVI Cable Restraint
- QDC
- VCATS Video Switch Unit with Aircraft-Mounted 3-Axis Accelerometers
- Parking Station for Module II end of QDC
- VCATS Cockpit Panel with Module II Connectors

Back-up

Key Issues

- Pilot Visual Performance (FOV, Resolution, Overlap)
- Performance Under G (Exit Pupil, Uplook)
- Safety for Ejection and Emergency Egress (Weight, CG, MMI, Profile)
- Pilot Acceptability (Fit, Comfort, Stability)
- Full Pilot Population Accommodation
- Life Support Equipment Compatibility (O2 Mask, Helmet, Visor, Chem/Bio, LEP, Comm)
- Display Integration (Symbology, Imagery)
- Sensor Fusion (I2, FLIR, MMWR)
- Aircraft Interfaces (HVI, CCP)

Key Issues (cont.)

- HMD and NVG Measurement
- Compatibility with Cockpit Displays and Avionics (HUD, ADI, HSI, Moving Map, Radar)
- Reliability, Maintainability, Commonality, Affordability, Producibility

Key Issues (cont.)

- **Operations**
  - Eye is the Critical Sensor - Must See Target/Countermeasures
  - Minimize System Latency Until Undetectable by Pilot
  - Prevent Helmet From Slipping Under High “G”
  - Reduce System Static Pointing Errors To Minimize Cueing Time
  - Develop Buffet Suppression Algorithms
  - Support Tactical Combat Turns
  - Modularize System - In-flight Interchangeability

Key Issues (cont.)

- Life Support Activities (LSAs)
  - Don’t Compromise Safety
  - Make Complex Electronics on Human Compatible with Common LSAs
  - Minimize Complications to the Standard Helmet Fit Process
  - Automate Helmet Checkout Prior to Flight
- Logistics Issues
  - Make Critical Component Replacement Reliable and Self-Calibrating
  - Assess All Development Items for Maintainability & Producibility

Display Characteristics
Brightness - References

- References:
- 1 Van Cott, Harold P., PH. D. and Kinkade, Robert G., Ph. D., Editors, Human Engineering Guide to Equipment Design (Revised Edition), American Institutes for Research, Washington, D.C., 1972
- 2. Melzer, James E., Moffitt, Kirk, Head-Mounted Displays Designing for the User, McGraw-Hill, New York, 1997.